PLASTIC PACKAGING MODELING: INTERACTIONS WITH FOOD. MODEL AND METHOD TO ESTIMATE THE SHELF LIFE OF OXYGEN-SENSITIVE FOOD PRODUCTS

Iván D. López, Omar A. Estrada, Juan C. Estefan, Alejandro Betancur
ICIPC® Instituto de Capacitación e Investigación del Plástico y el Caucho, Medellín - Colombia

Abstract

A model to estimate the shelf life in oxygen sensitive food products is proposed. The kinetics of oxygen consumption of the food product and the permeation properties of the package are considered. A novel method to characterize the oxygen consumption is discussed. Some results for an oxygen-sensitive product are presented. The model and method proposed are very useful for developing new products and for making decisions about the selection of film and packaging conditions according to the shelf life expectations.

Introduction

Shelf life is the maximum time that a food product can be stored without any appreciable deterioration in quality and acceptability. A model to estimate the shelf life is desirable to support the improvement and development of products. For the shelf life estimation of oxygen sensitive products, permeation properties of the package, the rate of oxygen consumption and the volume and initial amount of oxygen of the head space must be considered [3].

Some approaches to model the relation between oxygen and shelf life have been reported. Gomes et al.[2] and Conte et.al. [1] propose the use of mathematical models to predict vegetable breathing. Kanavouras and Coutelieris [5] predict the olive oil shelf life using a model that considers permeation, light, temperature and oxygen. DelNobile [8] proposes a model to predict potato chips shelf life considering oxygen and water vapor effects. Rodriguez et. al. consider [9] the rate of oxygen consumption to predict the shelf life of soft cheese.

Jena and Das propose a model to calculate the shelf life of coconut milk powder [4]. The model proposed in the present work is an improvement of this model, using a formulation that can be easily extrapolated to different package sizes and packaging and storing conditions.

The novel method and improved model proposed in this work can be applied to several food products with minor changes. It allows understanding how the barrier properties and the packaging conditions can affect the shelf life, and represents an important tool for the food and packaging industries.

Materials and methods

Glass containers are used for the oxygen consumption characterization (Figure 1). A fluorescence oxygen sensor was located on the inner wall of each container. The containers must be hermetic and translucent to allow the optic measurement of oxygen headspace. Each container is filled with the food product keeping the relation weight/volume of the original package. The atmosphere inside the container is modified using a mixture of oxygen and nitrogen, in order to control the initial amount of oxygen. The samples are located in a controlled temperature and humidity chamber. Periodically, the headspace is measured using the Optech – O2 Plantinum of Mocon.

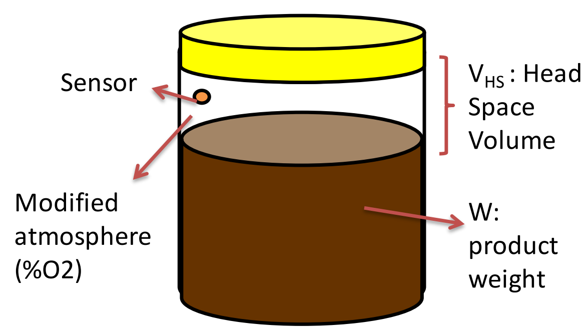

Figure 1 Scheme of the experimental setup to characterize the oxygen in the head space

From time to time, samples are evaluated using a sensory panel test to determine the critical amount of oxygen consumed or released by the food product at which the product is no longer fit for consumption.

For the packaging evaluation, an Ox-tran Model 2/10 was used to measure the oxygen transmission rate (OTR) of the package.

Model

Determination of the velocity of consumption of oxygen per unit of mass of food product

From the experimental setup, the percent of oxygen in the head space as a function of time is obtained. The amount of oxygen can be converted in mass units using the following equation, based on the ideal gas law:

$$W_{O_2}(t)=\frac{p\cdot V_{HS}\cdot M_w}{R\cdot T}\left(\%O_2(t)\right) \tag{1}$$

And can be represent in a dimensionless way dividing by the weight of product

$$\widehat{W}_{O_2}(t)=\frac{W_{O_2}(t)}{W_{product}} \tag{2}$$

The dimensionless amount of oxygen consumed as a function of time can be estimated subtracting from the original amount of oxygen the amount of oxygen of each time

$$\hat{W}_{O_{2c}}(t)=\hat{W}_{O_2}(0)-\hat{W}_{O_2}(t) \tag{3}$$

The data of the dimensionless amount of consumed oxygen can be approximated to the following model.

$$\hat{W}_{O_{2c}}(t)=\frac{a\cdot t}{1+b\cdot t} \tag{4}$$

where a represents the velocity of consumption at $t=0$, and a/b is the theorical oxygen consumption at $t=\infty$.

An example of experimental data and the fitted model (4) of an oxygen-sensitive product is presented in Figure 2.

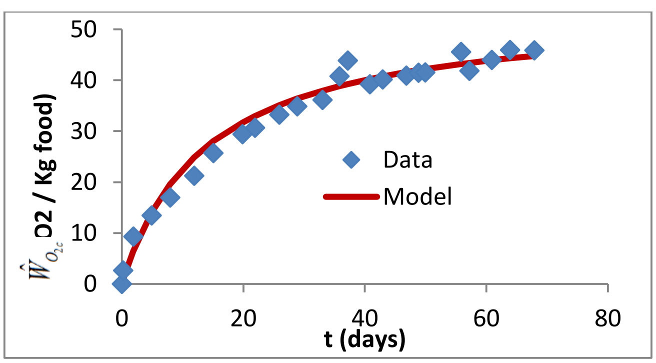

Figure 2 Dimensionless amount of oxygen consumed as a function of time

The velocity of consumption can be obtained from equation (4),

$$\dot{\hat{W}}_{O_{2c}}(t)=\frac{a}{1+b\cdot t}-\frac{a\cdot b\cdot t}{(1+b\cdot t)^2} \tag{5}$$

From equations (3) and (4),

$$t=\frac{\hat{W}_{O_{2c}}}{a-b\cdot\hat{W}_{O_{2c}}}=\frac{\hat{W}_{O_2}(0)-\hat{W}_{O_2}(t)}{a-b\cdot\left(\hat{W}_{O_2}(0)-\hat{W}_{O_2}(t)\right)} \tag{6}$$

Combining equations (5) and (6)

$$\dot{\hat{W}}_{O_{2c}}(t)=c_2\left(\hat{W}_{O_2}(t)\right)^2+c_1\left(\hat{W}_{O_2}(t)\right)+c_0 \tag{7}$$

where $c_2=\left(\frac{b^2}{a}\right)$, $c_1=-\frac{2b^2}{a}\hat{W}_{O_2}(0)+2b$ and

$$c_0=a-2b\cdot\hat{W}_{O_2}(0)+\frac{b^2}{a}\hat{W}_{O_2}{}^2(0)$$

Shelf life calculation

In the system composed of the food product and the package, the oxygen permeates through the package and is consumed or released by the product as illustrated in Figure 3.

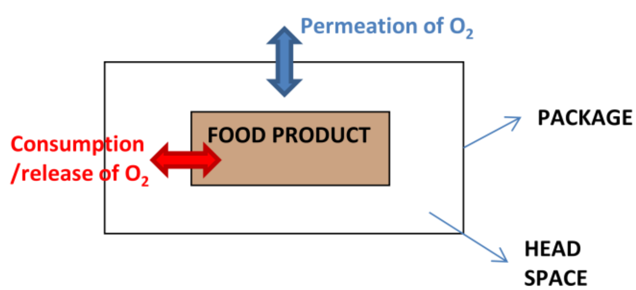

Figure 3 Scheme of the oxygen interaction in a package-food system

The mass balance of the oxygen of that system, assuming that the oxygen enters through the package and the food product consumes oxygen, is given by

$$\dot{\hat{W}}_{O_2}(t)=\dot{\hat{W}}_{O_{2p}}(t)-\dot{\hat{W}}_{O_{2c}}(t) \tag{8}$$

The velocity at which the oxygen permeates through the package per unit of mass of the food product is given by,

$$\dot{\hat{W}}_{O_{2p}}(t)=\left(\frac{P}{x}\right)^{*}\frac{A}{W}\left(p_{out}\cdot\%O_{2_{out}}-p_{in}\cdot\%O_{2_{in}}\right) \tag{9}$$

where

$$\%O_{2_{in}}=\frac{\hat{W}_{O_2}(t)\cdot R\cdot T\cdot W}{p_{in}\cdot V_{HS}\cdot M_w} \tag{10}$$

and

$$\left(\frac{P}{x}\right)^{*}=\frac{M_w\cdot p_{STP}}{R\cdot T_{STP}}\left(\frac{P}{x}\right) \tag{11}$$

where T_{STP} and p_{STP} are the standard conditions for temperature and pressure, respectively.

Using equations (7), (9) and (10), equation (8) can be rewritten as:

$$\frac{\partial\hat{W}_{O_2}(t)}{\partial t}=\left(\frac{P}{x}\right)^{*}\frac{A}{W}\begin{pmatrix}p_{out}\cdot\%O_{2_{out}}\\ -p_{in}\cdot\dfrac{\hat{W}_{O_2}(t)\cdot R\cdot T\cdot W}{p_{in}\cdot V_{HS}\cdot M_w}\end{pmatrix} \tag{12}$$

$$-c_2\left(\hat{W}_{O_2}(t)\right)^2+c_1\left(\hat{W}_{O_2}(t)\right)+c_0$$

Which can be numerical integrate using a explicit finite difference method to obtain,

$$\hat{W}_{O_2}{}^{i+1}=\Delta t\cdot\begin{pmatrix}\left(\dfrac{P}{x}\right)^{*}\dfrac{A}{W}\begin{pmatrix}p_{out}\cdot\%O_{2_{out}}\\ -p_{in}\cdot\dfrac{\hat{W}_{O_2}{}^{i}\cdot R\cdot T\cdot W}{p_{in}\cdot V_{HS}\cdot M_w}\end{pmatrix}\\ -c_2\left(\hat{W}_{O_2}{}^{i}\right)^2+c_1\left(\hat{W}_{O_2}{}^{i}\right)+c_0\end{pmatrix}+\hat{W}_{O_2}{}^{i} \tag{13}$$

The previous equation should be solved until the value of the amount of oxygen consumed by the food product per unit of mass ($\hat{W}_{O_{2c}}{}^{i+1}=\hat{W}_{O_2}{}^{0}-\hat{W}_{O_2}{}^{i+1}$) reaches the critical value defined by the sensorial panel test.

The nomenclature used in this paper is summarized in Table 1.

Table 1 Nomenclature

$\%O_2$	Percentage amount of oxygen in the head space
W_{O_2}	Weight of oxygen within the head space
$\hat{W}_{O_2}$	Weight of oxygen within the head space per unit of mass of food product
$\hat{W}_{O_{2c}}$	Amount of oxygen consumed by the product per unit of mass of food
$\dot{\hat{W}}_{O_{2c}}$	Velocity of oxygen consumption per unit of mass of food
$\dot{\hat{W}}_{O_{2p}}$	Velocity of permeation of oxygen per unit of mass of food.
p	Pressure . p_{in} : inside the package. p_{out} : outside the package
T	Temperature
V_{HS}	Head space Volume
R	Universal Gas Constant
W	Weight of the food product
$\left(\frac{P}{x}\right)$	Permeation coefficient given in units of : volume of gas at STP conditions per unit of time, area and pressure gradient.
$\left(\frac{P}{x}\right)^{*}$	Permeation coefficient given in units of gas mass per unit of time, area and pressure gradient.
A	Package area
M_w	Molecular weight (3200 mg/mol for oxygen)
c_0, c_1, c_2	Coefficients for the oxygen consumption velocity model

The model was used with several oxygen-sensitive food products, obtaining good results. For a specific product, the sensorial panel test defined that the food can be stored without any appreciable deterioration in quality and acceptability, until it consumes 162 ppm of oxygen. Equation (13) was solved until that critical value was reached, obtaining predictions of shelf life for different barrier values. The results are presented in Figure 4.

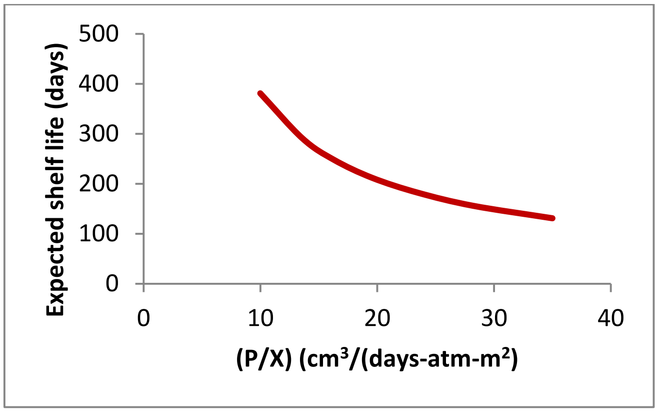

Figure 4 Expected shelf life as a function of (P/x)

For this product that is in the market, a film with a permeation coefficient of 19.5 cm^3_{STP}/(atm-day-m^2) and a modified atmosphere are used. The model estimates a shelf life of 212 days (7 months), very close to the real shelf life value that is between 7 and 8 months.

Additionally to the film selection, this model can be used to study the effect of other packaging engineering parameters on shelf life, such as the head space volume, the package geometry, the amount of oxygen in the head space, the packaged weight and the storage temperature.

Conclusions

A model and experimental characterization method to predict the shelf life of oxygen-sensitive food products was proposed. The results obtained with this model are in good agreement with direct shelf life measurements. The model and method proposed are very useful for developing new products and for making decisions about the selection of film and packaging conditions according to the shelf life expectations.

Acknowledgements

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